DECLARATION

I, Tsuyoshi Matsukawa, of Yanagida & Associates, 7F Shin-Yokohama KS Bldg., 3-18-3 Shin-Yokohama, Kohoku-ku, Yokohama-shi, Japan, hereby certify that I understand both English and Japanese, that the translation is true and correct, and that all statements are being made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

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【Name of the Document】 Specification

【Title of the Invention】 SEMICONDUCTOR LASER AND METHOD OF MANUFACTURING THE SAME

【Claims】

【Claim 1】 A semiconductor laser comprising an active region which includes at least a quantum well layer and upper and lower optical waveguide layers and is of $In_xGa_{1-x}As_yP_{1-y}$ ($0 \leqq x \leqq 1$、$0 \leqq y \leqq 1$) and upper and lower cladding layers formed of AlGaAs, wherein the improvement comprises that

at least one of the optical waveguide layers is not smaller than 0.25μm in thickness, and

a part of the upper cladding layer on the upper optical waveguide layer is selectively removed up to the interface of the upper cladding layer and the upper optical waveguide layer.

【Claim 2】 A semiconductor laser as defined in Claim 1 in which the structure where a part of the upper cladding layer on the upper optical waveguide layer is selectively removed up to the interface of the upper cladding layer and the upper optical waveguide layer forms a ridge structure.

【Claim 3】 A method of manufacturing a semiconductor laser defined in Claim 1 comprising the steps of

forming at least one of the optical waveguide layers in thickness not smaller than 0.25μm,

forming the upper cladding layer of AlGaAs on the upper optical waveguide layer and

selectively removing by etching a part of the upper cladding layer on the upper optical waveguide layer up to the interface of the upper cladding layer and the upper optical waveguide layer.

【Detailed Description of the Invention】

【Field of the Invention】

This invention relates to a semiconductor laser, and more particularly to a semiconductor laser having an active region which includes at least a quantum well layer and an optical waveguide layer and is of $In_xGa_{1-x}As_yP_{1-y}$ ($0 \leqq x \leqq 1$、$0 \leqq y \leqq 1$).

This invention further relates to a method of manufacturing such a semiconductor laser.

【Prior Art】

A semiconductor laser has come to be used in wider and wider fields. Especially a semiconductor laser which has an GaAs substrate and oscillates in 0.7 to 1.1μm band has come to be used, as its output power increases, not only for an optical disc and a laser printer but also for a light source for pumping a solid state laser, a fiber amplifier and a fiber laser, a primary light source for generating a second harmonic, a light source for thermally recording an image on a heat-sensitive material, for instance, in printing, a light source for medical use, a light source for laser machining and laser soldering, and the like.

In these applications, it is extremely important that the semiconductor laser can output high power. In a single mode laser which is narrow in width (not larger than about 5μm), those which are 500mW or more in the maximum light output and 150mW or more in the practical light output have been reported as, for instance, a light source for pumping a fiber amplifier oscillating, for instance, at 0.98μm or 1.02μm. Further it has been reported that, in multiple-mode lasers which are about 50μm or more in stripe width, the catastrophic optical damage (COD) when the oscillation wavelength is, for instance, 0.87μm is 11.3W in the case of an element which is 100μm in stripe width and is 16.5W in the case of an element

which is 200μm in stripe width. See "Electronics Letters", vol.34, No.2, P.184 (1998), (S.O'Brien, H. Zhao and R. J. Lang).

These inventors have proposed a semiconductor laser in which catastrophic failure due to oxidization of Al is prevented by freeing the vicinity of the light emission region (a quantum well layer and an optical waveguide layer which is adjacent to the quantum well layer and forms a barrier) from Al and at the same time, an AlGaAs layer is employed as a cladding layer in order to prevent deterioration in temperature characteristics due to leakage of electrons from the active region. With this arrangement, the semiconductor laser can operate at high output power. See "Japanese Journal of Applied Physics", Vol. 34, No. 9B, p. L1175 (1995), (T. Fukunaga, M. Wada, H. Asano and T. Hauakawa). This will be referred to as "reference 1", hereinbelow.

【Problems to be Solved by the Invention】

In the semiconductor laser which these inventors have proposed, the thickness of each InGaP cladding layer is 0.1μm and the optical confinement factor (Γ) to the active layer quantum well for a laser beam is relatively large. Accordingly, when a device which was 50μm in stripe width was aged under 500mW at 50°C in an APC (automatic power control) mode, deterioration rate of the drive current was relatively large and was $5x10^{-5}h^{-1}$ in median. Further when a device which was 200μm in stripe width was aged under 2000mW at 25°C in an APC mode, deterioration rate of the drive current was also $5x10^{-5}h^{-1}$ in median.

Such high output power semiconductor lasers having a relatively wide stripe comes to stop oscillating when the drive current increases by about 5%. Accordingly the service life of the latter semiconductor laser is estimated at about 1000 hours in median,

which is practically insufficient. Further since being of a gain waveguide type, the conventional semiconductor lasers are disadvantageous in that fundamental oscillation characteristics such as the current versus light output characteristics become unstable due to fluctuation in transverse mode.

Further there has been known a semiconductor laser in which the output power is increased by employing Al-free material different from that disclosed in "reference 1" and at the same time reducing the optical confinement factor (Γ) to the active layer quantum well for a laser beam by increasing the thickness of the optical waveguide layer. See "Appl. Phys. Lett.", Vol. 72, No.1, P. 4, (J.K. Wade, L. J. Mawst, D. Botez. R.F. Nabiev, M. Jansen and L. A. Morris) (reference 2) and "SPIE Proceeding", Vol. 3001, p. 2 (1997), (M.A. Emanuel, J. A. Skidnore and R. J. Beach) (reference 3).

However, as disclosed in "reference 1", especially in the wavelength range not longer than 850nm, temperature characteristics deteriorate due to leakage of electrons into a p-type cladding layer when the cladding layer is formed of a material free from Al. This is because electron barrier cannot be sufficient even if InGaP is used which is the largest in forbidden band width in materials which can be lattice-matched with the GaAs substrate.

Further when producing such a refractive index waveguide type element, it is difficult to stop etching at the interface of an InGaP cladding layer and an InGaAsP optical waveguide layer since these layers resemble each other in chemical properties.

Further there has been reported an element in which the cladding layer is formed of InGaAlP for the purpose of suppressing deterioration in temperature characteristics due to leakage of electrons into the p-type cladding layer, as disclosed in "reference 2". However in "reference 2", only the gain waveguide type is

mentioned and optimization for the refractive index waveguide type is not mentioned.

Further, the p-type InGaAlP is generally disadvantageous as compared with AlGaAs in that it is high in electric resistance and thermal resistance. Reliability when such a material is used has not been discussed. When the active layer is exposed to atmosphere on a GaAs substrate during production of a refractive index waveguide type element, crystallizability on the surface thereof deteriorates and remarkable deterioration of the exposed part of the crystal interface due to non-emission recombination of carriers is generated.

Accordingly, a method in which etching is carried out up to a portion immediately above the active layer has been generally employed. In this case, as in a ridge waveguide type laser shown in Figure 2, etching is carried out so that the upper cladding layer is left in a small thickness (about 0.1 to 0.3μm) by controlling the etching time.

However such etching time control is disadvantageous in that reproducibility deteriorates due to fluctuation in etching conditions and thickness of the cladding layer from wafer to wafer. In order to overcome this problem, there has been proposed a structure in which an etching stop layer is inserted as shown in Figure 3. See United States Patent No. 4,567,060 (reference 4).

For example, in the case where an AlGaAs cladding layer and an InGaAsP active region are combined, by inserting an InGaP etching stop layer (about 1 to 5nm in thickness), which is lattice-matched with the GaAs substrate, into the upper cladding layer as shown in Figure 3, it becomes feasible to stop etching of the AlGaAs at the InGaP etching stop layer in various etching methods.

However an InGaP layer inserted into a p-type AlGaAs cladding

layer sometimes deteriorates crystallization, which results in increase in electric resistance and/or built-in voltage. This is supposed because As on the surface of the AlGaAs is substituted by P to form AlGaAsp on the crystal interface of AlGaAs and InGaP at the beginning of crystal growth.

In view of the foregoing observations and description, the primary object of the present invention is to provide a high power semiconductor laser in which the service-life elongating effect of using an Al-free active layer material is enhanced and the long-term reliability is improved.

Another object of the present invention is to provide a method of manufacturing such a high power semiconductor laser.

【Means for Solving the Problems】

The semiconductor laser in accordance with the present invention comprises an active region which includes at least a quantum well layer and upper and lower optical waveguide layers and is of $In_xGa_{1-x}As_yP_{1-y}$ ($0 \leqq x \leqq 1$、$0 \leqq y \leqq 1$) free from Al and upper and lower cladding layers formed of AlGaAs, and is characterized in that

at least one of the optical waveguide layers is not smaller than 0.25μm in thickness, and

a part of the upper cladding layer on the upper optical waveguide layer is selectively removed up to the interface of the upper cladding layer and the upper optical waveguide layer.

The method of manufacturing a semiconductor laser in accordance with the present invention is for manufacturing the semiconductor laser of the present invention, and is characterized by the steps of

forming at least one of the optical waveguide layers in thickness not smaller than 0.25μm,

forming the upper cladding layer of AlGaAs on the upper optical waveguide layer and

selectively removing by etching a part of the upper cladding layer on the upper optical waveguide layer up to the interface of the upper cladding layer and the upper optical waveguide layer.

【Effect of the Invention】

In the semiconductor laser of the present invention with arrangement described above, the light density (Γ/d) in the quantum well portion is reduced by virtue of the optical waveguide layer not smaller than 0.25μm in thickness, whereby internal loss is reduced and the deterioration rate in the drive current during APC aging which increases in proportion to the fourth or more power of the light density is reduced.

The semiconductor laser of the present invention is a refractive index waveguide type element since a part of the upper cladding layer on the upper optical waveguide layer is selectively removed up to the interface of the upper cladding layer and the upper optical waveguide layer.

When such a refractive index waveguide type element structure, the upper cladding layer is removed by etching inside or outside the stripe. When removing by etching a part of the upper cladding layer, conventionally, there is employed a method in which a part of the upper cladding layer is left unetched by providing an etching stop layer which differs from the upper cladding layer in composition and/or component atoms and is etched at a rate greatly smaller than the upper cladding layer ("reference 4"), or a method in which a part of the upper cladding layer is left unetched by controlling the etching time (See "reference 5": "Applied Physics Letters", Vol. 51, Bo. 10, p. 707 (1987), (T. Hayakawa, T. Suyama, K. Takahasi,

M. Kondo, S. Yamamoto, and T. Hijikata)).

To the contrast, in accordance with the method of the present invention, the upper cladding layer is removed up to the optical waveguide layer having an increased thickness. By using an organic etching solution such as of sulfuric acid or citric acid, etching can be stopped at the optical waveguide layer. By stopping etching without use of an etching stop layer which adversely affects properties of the elements, the refractive index waveguide structure can be produced with good reproducibility, whereby fundamental oscillation characteristics can be stabilized.

Conventionally since the optical waveguide layer is small in thickness, i.e., about 0.1μm, the cladding layer is left in a thickness of 0.1 to 0.2μm in order to suppress deterioration in crystallization without deteriorating the quality of the active layer. However, when the thickness of the optical waveguide layer is not smaller than 0.25μm, deterioration in crystallization does not occur even if the cladding layer is removed to the optical waveguide layer.

Further in the method of the present invention, since the distance between the quantum well in the active layer and the surface of the optical waveguide layer at the part where the cladding layer is removed is increased, damage to the active layer during formation of the refractive index waveguide structure can be suppressed.

As can be understood from the description above, the service-life elongating effect of using an Al-free active layer material can be enhanced and the long-term reliability is greatly improved in accordance with the present invention. Especially, since the semiconductor laser of the present invention has high quality properties as a refractive index waveguide type laser and, at the same time, is very small in variation of properties with time,

it can improve system reliability when used as a light source for the field of image forming where noise and/or change in intensity and/or shape of the beam give rise to a problem.

As application to the field of image forming, the semiconductor laser of the present invention can be applied, for instance, to a printing system where a semiconductor laser pumped solid state laser is employed, or to a visible or ultraviolet light source for a printer or an image scanner where a semiconductor laser pumped solid state laser is employed in combination with a SHG. In the field of a printer using heat-sensitive recording material where a semiconductor laser beam is used as a writing light beam, several to about one hundred high power semiconductor lasers are used in one system, and accordingly, the semiconductor lasers of the present invention greatly contribute to improvement of system reliability.

Further in the semiconductor laser of the present invention, increase of the thickness of the optical waveguide layer reduces trailing of evanescent light oozing into the cladding layer and accordingly, the upper cladding layer can be reduced in thickness without adverse influence of absorption of the capping layer. Accordingly, the thickness of the upper cladding layer, which conventionally should be not smaller than 1.5μm, may be reduced to not larger than 1μm. When the upper cladding layer is of such a small thickness, unevenness after etching which the refractive index waveguide structure inherently has can be small, which facilitates the subsequent lithography process and improves the accuracy of the lithography process. Further since the irregularity on the surface of a finished device is reduced, uniform wax wetting is obtained during chip bonding, which improves heat dissipation properties.

【Embodiments】

Embodiments of the invention will be explained with reference to the drawings. In Figure 1, a semiconductor laser in accordance with a first embodiment of the present invention comprises an n-GaAs buffer layer 2 (doped with $1x10^{18}cm^{-3}$ Si, 0.5μm thick), an n-$Al_{0.63}Ga_{0.37}As$ lower cladding layer 3 (doped with $1x10^{18}cm^{-3}$ Si, 1μm thick), an undoped SCH active layer 4, a p-$Al_{0.63}Ga_{0.37}As$ upper cladding layer 5 (doped with $1x10^{18}cm^{-3}$ Zn, 1μm thick), a p-GaAs capping layer 6 (doped with $2x10^{19}cm^{-3}$ Zn, 0.3μm thick), and a SiO_2 insulating film 7 formed one on another on one side of an n-GaAs substrate 1 (doped with $2x10^{18}cm^{-3}$ Si).

The undoped SCH active layer 4 comprises an $In_{0.48}Ga_{0.52}P$ lower optical waveguide layer 4a (undoped, 0.4μm in thickness Wg), an $In_{0.13}Ga_{0.87}As_{0.75}P_{0.25}$ quantum well layer 4b (undoped, 10nm thick) and an $In_{0.48}Ga_{0.52}P$ upper optical waveguide layer 4c (undoped, 0.4μm in thickness Wg).

A method manufacturing this semiconductor laser will be described, hereinbelow. An n-GaAs buffer layer 2, an n-$Al_{0.63}Ga_{0.37}As$ lower cladding layer 3, an undoped SCH active layer 4, a p-$Al_{0.63}Ga_{0.37}As$ upper cladding layer 5 and a p-GaAs capping layer 6 are first formed one on another in this order on one side of an n-GaAs substrate 1 by low-pressure MOCVD.

Then a mesa stripe structure which is 200μm in bottom width is formed by photolithography and chemical etching by use of a 20:1:1 mixture of H_2SO_4, H_2O_2 and H_2O. At this time, the p-$Al_{0.63}Ga_{0.37}As$ upper cladding layer 5 is etched at a rate 20-th or more as large as that at which the $In_{0.48}Ga_{0.52}P$ upper optical waveguide layer 4c is etched. By virtue of this fact, the mesa etching can be stopped just above the $In_{0.48}Ga_{0.52}P$ upper optical waveguide layer 4c with good reproducibility.

Thereafter, a SiO_2 insulating film 7 is formed by plasma CVD,

and a part of the SiO_2 insulating film 7 on the upper surface of the mesa in a region within 1 to 5μm from opposite edges of the mesa is etched and removed by photolithography and etching by use of dilute HF.

Then a p-side electrode 8 (Ti/Pt/Au) is formed by deposition and heat treatment, and the bottom surface of the GaAs substrate 1 is polished to thin the GaAs substrate 1 to about 100 to 150μm. Finally an n-side electrode 9 (AuGe/Ni/Au) is formed by deposition and heat treatment.

A laser bar which is 1.5mm in resonator length and about 1.5cm in length is cut out from the wafer by scribe with a diamond needle and cleavage, and the light radiating end face and the back end face are applied with optical coating films so that their reflectances are 20% and 95%, respectively. Finally the laser bar is cut into a plurality of laser chips by scribe with a diamond needle and cleavage. Each laser chip is fixed to a copper block by soldering the p-side electrode to the copper block by In solder.

The semiconductor laser produced in this manner oscillates at about 809nm by a threshold current of 660 to 700mA and can operate at a high output power of not lower than 2W. Figure 5 shows change with time of the drive current for this laser when the laser is driven under 2W at 25°C in an APC mode. As can be seen from Figure 5, the laser operates very stably.

In order to prove the effect of the present invention, detailed comparison experiments were carried out. The result is as follows.

In a first experiment, comparison semiconductor laser elements which were the same as the semiconductor laser of the first embodiment except that the thickness Wg of the InGaP optical waveguide guide layer differed from that of the first embodiment were produced and their reliability was evaluated. Figures 6 to 8

show change with time of the drive current for the comparison lasers, which were 0.11μm, 0.25μm and an 0.6μm in thickness Wg of the optical waveguide guide layer respectively, when the lasers were driven under 2W at 25°C in an APC mode. As can be seen from Figures 6 to 8, when the thickness Wg of the optical waveguide guide layer was smaller than 0.25μm, deterioration of the drive current was large (Figure 6), while when the thickness Wg of the optical waveguide guide layer was not smaller than 0.25μm, deterioration of the drive current was relatively small and the lasers operated stably (Figures 7 and 8).

Figure 9 shows the relation between the deterioration rate of the drive current (increase of drive current/drive current/time) in median and the thickness Wg of the optical waveguide layer in a stabilized state after the lasers are operated for 200 hours. As can be seen from Figure 9, the deterioration rate of the drive current is very low.

Figure 4 shows calculated values of the relation between d/Γ which is a value proportional to the reciprocal of the light density in the quantum well of the active layer of the structure in accordance with the present invention (d: thickness of the quantum well in μm, Γ: optical confinement factor to the active layer quantum well for a laser beam) and the thickness Wg of the optical waveguide layer. As can be seen from Figure 4, when the thickness Wg of the optical waveguide layer was in the range of not smaller than 0.25μm, the light density in the quantum well decreased monotonically with increase of the thickness Wg of the optical waveguide layer, which proved improvement in reliability.

When the thickness Wg was 0.6μm, the deterioration rate was larger than when the thickness Wg was 0.4μm due to increase of the drive current by about 10%. Further when the thickness Wg was not smaller than 0.25μm, an excellent reliability was obtained, which

proved that reliability was not deteriorated even if an insulated film such as SiO_2 was formed in contact with the optical waveguide layer without intervening therebetween an upper cladding layer left there in a small thickness as a protective layer as in the conventional semiconductor lasers shown in Figures 2 and 3. Further as shown in Figure 15, current versus light out characteristics without kink could be obtained up to a high output range and both the far-field image and the near-field image were stable.

In a second experiment, the catastrophic optical damages of the aforesaid laser elements were measured. As shown in Figure 10, the catastrophic optical damage hardly changed with change of the thickness Wg of the optical waveguide layer. This proves that with the arrangement of the present invention, the catastrophic optical damage does not increase with increase of the thickness Wg of the optical waveguide layer as in the example disclosed in "reference 2", that is, the catastrophic optical damage is independent from the light density in the active layer.

In a third experiment, three kinds of laser elements which were the same as the conventional element shown in Figure 6 in structure, were 0.11μm in thickness Wg of the optical waveguide layer and were respectively 11%, 20% and 30% in reflectance Rf of the light radiating end face were prepared and compared.

The relation between the drive current deterioration rate in median and the internal light density at the light radiating end face when the laser was driven under 1.8W at 25°C in an APC mode was measured for each laser. As can be seen from Figure 11, the drive current deterioration rate greatly increases substantially in proportion to the fourth power of the internal light density at the light radiating end face and greatly depends upon the whole internal light intensity.

In a fourth experiment, Rf dependency of the catastrophic optical damage was evaluated for laser elements which were 0.11μm in the thickness Wg of the optical waveguide layer. As shown in Figure 12, the catastrophic optical damage was proportional to the internal light power.

The result of the aforesaid experiments shows that with the arrangement of the present invention, though the deterioration rate depends upon the light density in the quantum well of the active layer, the catastrophic optical damage was substantially proportional to the whole internal light power.

As a fifth example, factors which governed the internal loss ($\alpha i [cm^{-1}]$) were investigated on the basis of the slope efficiency for various laser elements. The experiment was carried out by use of laser elements having an oxide film stripe structure of 50μm width for the purpose of material evaluation. Figure 13 shows the dependency of the slope efficiency on the number of the quantum wells Nw (Nw=1~4) with the total thickness of the active layer (including quantum wells (10nm wide), barrier layers (undoped InGaP the same as that of the optical waveguide layers, 10nm thick) parting the quantum wells and optical waveguide layers) fixed to 0.23μm.

The slope efficiency is proportional to the external differential quantum efficiency (η_d) for the whole radiating light. The external differential quantum efficiency η_d is expressed by the following formula (1).

$$\eta_i \frac{\ln\left(\frac{1}{\sqrt{R_f R_r}}\right)}{\alpha_i L + \ln\left(\frac{1}{\sqrt{R_f R_r}}\right)}$$

wherein η_i represents the internal differential quantum efficiency,

Rf represents the reflectance of the light radiating end face, Rr represents the reflectance of the rear end face, and L represents the length of the resonator. Actually, only light radiated through the front end face is measured and utilized. The slope efficiency is related to the external differential quantum efficiency η_d as

$$\frac{L_f}{L_r}=\sqrt{\frac{R_r}{R_f}}\frac{(1-R_f)}{(1-R_r)}$$

from the following relation between the amount of light radiated from the front end face Lf and that radiated from the read end face Lr.

$$\frac{L_f}{L_f+L_r}\eta_d$$

In the case of a single-quantum well, it has been found that α_i=2cm^{-1}, and η_i=0.7 when Wg=0.11μm from a result of measurement of resonator length dependency of the slope efficiency carried out separately. The calculated values in Figure 13 were obtained letting μ_i=0.7 (constant) and α_i=Nwx2(cm^{-1}) and well conform to the result of the experiment. Accordingly, the residual loss in the semiconductor laser of the present invention may be considered to be mainly governed by loss by the quantum wells themselves.

Further single quantum well laser elements (Nw=1) and double quantum well laser elements (Nw=2) which were different from each other in the thickness Wg of the optical waveguide layer were prepared and the slope efficiency of each laser element was measured. As shown in Figure 14, the result of the measurement conformed to the calculated values in tendency that the internal loss increased in proportion to the amount of light in the quantum well. This supports that the residual loss in the semiconductor laser of the present

invention is mainly governed by loss by the quantum wells themselves.

The result of the experiments shows that in the semiconductor lasers in accordance with the present invention, the deterioration mechanism and the internal loss are due to the inside of the active layer and greatly depend upon the light power in the active layer. Accordingly, these factors can be improved by making the thickness Wg of the optical waveguide layer not smaller than 0.25μm.

A semiconductor laser in accordance with a second embodiment of the present invention will be described with reference to Figure 16, hereinbelow. In Figure 16, the semiconductor laser in accordance with the second embodiment of the present invention comprises an n-GaAs buffer layer 42 (doped with $1x10^{18}cm^{-3}$ Si, 0.5μm thick), an n-$Al_{0.55}Ga_{0.45}As$ lower cladding layer 43 (doped with $1x10^{18}cm^{-3}$ Si, 1μm thick), an undoped SCH active layer 44, an n-$Al_{0.65}Ga_{0.35}As$ current blocking layer 45 (doped with $1x10^{18}cm^{-3}$ Si, 0.8μm thick), an n-GaAs protective layer 46 (doped with $1x10^{18}cm^{-3}$ Si, 0.01μm thick), a p-$Al_{0.55}Ga_{0.45}As$ upper cladding layer 47 (doped with $1x10^{18}cm^{-3}$ Zn, 1μm thick), and a p-GaAs capping layer 48 (doped with $2x10^{19}cm^{-3}$ Zn, 0.3μm thick) formed one on another on one side of an n-GaAs substrate 41 (doped with $2x10^{18}cm^{-3}$ Si).

The undoped SCH active layer 44 comprises an $In_{0.48}Ga_{0.52}P$ lower optical waveguide layer 44a (undoped, 0.25μm in thickness Wg), an $In_{0.13}Ga_{0.87}As_{0.75}P_{0.25}$ quantum well layer 44b (undoped, 10nm thick) and an $In_{0.48}Ga_{0.52}P$ upper optical waveguide layer 44c (undoped, 0.25μm in thickness Wg).

A method manufacturing this semiconductor laser will be described, hereinbelow. In this embodiment, unlike in the first embodiment, the laser is produced by two-step low-pressure MOCVD. That is, an n-GaAs buffer layer 42, an n-$Al_{0.55}Ga_{0.45}As$ lower cladding layer 43, an undoped SCH active layer 44, an n-$Al_{0.65}Ga_{0.35}As$ current

blocking layer 45 and an n-GaAs protective layer 46 are first grown one on another in this order on one side of an n-GaAs substrate 41 by low-pressure MOCVD.

Then a mesa stripe channel which is 200μm in bottom width is formed by photolithography and chemical etching by use of a 20:1:1 mixture of H_2SO_4, H_2O_2 and H_2O. At this time, the etching is stopped just above the $In_{0.48}Ga_{0.52}P$ upper optical waveguide layer 44c since the undoped SCH active layer 44 comprises the $In_{0.48}Ga_{0.52}P$ lower optical waveguide layer 44a (undoped, 0.25μm in thickness Wg), the $In_{0.13}Ga_{0.87}As_{0.75}P_{0.25}$ quantum well layer 44b (undoped, 10nm thick) and the $In_{0.48}Ga_{0.52}P$ upper optical waveguide layer 44c.

Then a p-$Al_{0.55}Ga_{0.45}As$ upper cladding layer 47 and a p-GaAs capping layer 48 are grown in sequence by low-pressure MOCVD.

Thereafter, a p-side electrode 49 is formed, the GaAs substrate 41 is polished, an n-side electrode 50 is formed, a laser bar is cut out, the light radiating end face and the back end face are applied with optical coating films, and the laser bar is cut into a plurality of laser chips in the manner similar to that in the first embodiment.

A semiconductor laser in accordance with a third embodiment of the present invention will be described with reference to Figure 17, hereinbelow. In Figure 17, the semiconductor laser in accordance with the third embodiment of the present invention comprises an n-GaAs buffer layer 62 (doped with $1x10^{18}cm^{-3}$ Si, 0.5μm thick), an n-$Al_{0.6}Ga_{0.4}As$ lower cladding layer 63 (doped with $1x10^{18}cm^{-3}$ Si, 1μm thick), an undoped SCH active layer 64, an n-$Al_{0.65}Ga_{0.35}As$ current blocking layer 66 (doped with $1x10^{18}cm^{-3}$ Si, 0.8μm thick), a p-GaAs protective layer 67 (doped with $1x10^{18}cm^{-3}$ Si, 0.01μm thick), a p-$Al_{0.6}Ga_{0.4}As$ first upper cladding layer 65 (doped with $1x10^{18}cm^{-3}$ Zn, 1μm thick), a p-$Al_{0.6}Ga_{0.4}As$ second upper cladding layer 68 (doped

with $1x10^{18}cm^{-3}$ Zn, 1μm thick), and a p-GaAs capping layer 69 (doped with $2x10^{19}cm^{-3}$ Zn, 0.3μm thick) formed one on another on one side of an n-GaAs substrate 61 (doped with $2x10^{18}cm^{-3}$ Si).

The undoped SCH active layer 64 comprises an $In_{0.48}Ga_{0.52}P$ lower optical waveguide layer 64a (undoped, 0.25μm in thickness Wg), an $In_{0.13}Ga_{0.87}As_{0.75}P_{0.25}$ quantum well layer 64b (undoped, 10nm thick) and an $In_{0.48}Ga_{0.52}P$ upper optical waveguide layer 64c (undoped, 0.25μm in thickness Wg).

A method manufacturing this semiconductor laser will be described, hereinbelow. In this embodiment, the laser is produced by three-step low-pressure MOCVD. That is, an n-GaAs buffer layer 62, an n-$Al_{0.55}Ga_{0.45}As$ lower cladding layer 63, an undoped SCH active layer 64, a p-$Al_{0.6}Ga_{0.4}As$ first upper cladding layer 65 and a p-GaAs protective layer 67 are grown one on another in this order on one side of an n-GaAs substrate 41 by first low-pressure MOCVD.

Thereafter, a SiO_2 film 0.25μm thick is formed by plasma CVD, and a stripe-like SiO_2 mask 200μm wide is formed by photolithography and etching by use of dilute HF. Then a mesa stripe structure which is 200μm in bottom width is formed by chemical etching by use of a 20:1:1 mixture of H_2SO_4, H_2O_2 and H_2O.

Then an n-$Al_{0.65}Ga_{0.35}As$ current blocking layer 66 and a p-GaAs protective layer 67 are grown by second low-pressure MOCVD. At this time, though polycrystal grows also on the SiO_2 mask, it can be removed by next etching. Then short etching by use of a mixture of H_2SO_4, H_2O_2 and H_2O is carried out and the SiO_2 mask is removed by dilute HF.

After etching the p-GaAs protective layer 67 for a short time with a mixture of H_2SO_4, H_2O_2 and H_2O, a p-$Al_{0.6}Ga_{0.4}As$ second upper cladding layer 68 and a p-GaAs capping layer 69 are grown by third low-pressure MOCVD.

Thereafter, a p-side electrode 70 is formed, the GaAs substrate 61 is polished, an n-side electrode 71 is formed, a laser bar is cut out, the light radiating end face and the back end face are applied with optical coating films, and the laser bar is cut into a plurality of laser chips in the manner similar to that in the first embodiment.

Though the present invention is described above in conjunction with a broad stripe semiconductor laser having a stripe 200μm wide, the present invention can also be applied to multiple transverse mode semiconductor lasers having a broad stripe of various widths or a single transverse mode semiconductor lasers which are not larger than about 6μm in width of the stripe.

The active layer which includes at least a quantum well layer and upper and lower optical waveguide layers has only to be of $In_xGa_{1-x}As_yP_{1-y}$ ($0 \leqq x \leqq 1$、$0 \leqq y \leqq 1$), and a strain layer which is not lattice-matched with the substrate may be partly used. Further the upper and lower optical waveguide layers on opposite sides of the quantum well layer may be of different thicknesses. In this case, the quantum well layer is shifted from a position in which the light intensity is maximized and the optical confinement factor Γ is reduced, and accordingly, the light density in the quantum well can be reduced when the thicker one of the optical waveguide layers is not smaller than 0.25μm.

【Brief Description of the Drawings】

【Figure 1】

A schematic view showing the layer arrangement of a ridge waveguide type semiconductor laser in accordance with a first embodiment of the present invention.

【Figure 2】

A schematic view showing the layer arrangement of an example of a conventional ridge waveguide type semiconductor laser.

【Figure 3】

A schematic view showing the layer arrangement of another example of a conventional ridge waveguide type semiconductor laser.

【Figure 4】

A view showing the dependency on the thickness of the optical waveguide layer of d/Γ which is a value proportional to the reciprocal of the light density in the quantum well.

【Figure 5】

A view showing change with time of the drive current for a ridge waveguide type semiconductor laser in accordance with the present invention where the optical waveguide layer is 0.4μm in thickness.

【Figure 6】

A view showing change with time of the drive current for a conventional ridge waveguide type semiconductor laser.

【Figure 7】

A view showing change with time of the drive current for a ridge waveguide type semiconductor laser in accordance with the present invention where the optical waveguide layer is 0.25μm in thickness.

【Figure 8】

A view showing change with time of the drive current for a ridge waveguide type semiconductor laser in accordance with the present invention where the optical waveguide layer is 0.6μm in thickness.

【Figure 9】

A view showing the dependency on the thickness of the optical waveguide layer of the drive current deterioration rate in a ridge waveguide type semiconductor laser.

【Figure 10】

A view showing the dependency on the thickness of the optical waveguide layer of the catastrophic optical damage of a ridge waveguide type semiconductor laser.

【Figure 11】

A view showing the relation between the drive current deterioration rate and the internal light power in a conventional ridge waveguide type semiconductor laser.

【Figure 12】

A view showing comparison of measured values of catastrophic optical damage (COD) and the calculated value of internal light power at the front end face of a conventional ridge waveguide type semiconductor laser for various reflectances of the coating applied to the front end face.

【Figure 13】

A view showing comparison of measured relation between the number of quantum wells and the slop efficiency and theoretical relation of the same.

【Figure 14】

A view showing measured values and calculated values of dependency on the thickness of the optical waveguide layer of the slope efficiency of a single quantum well semiconductor laser and a double quantum well semiconductor laser.

【Figure 15】

A view showing the current versus light output

characteristics of a ridge waveguide type semiconductor laser in accordance with the present invention.

【Figure 16】

A schematic view showing the layer arrangement of a ridge waveguide type semiconductor laser in accordance with a second embodiment of the present invention.

【Figure 17】

A schematic view showing the layer arrangement of a ridge waveguide type semiconductor laser in accordance with a third embodiment of the present invention.

【Description of Reference Characters】

1 n-GaAs substrate

2 n-GaAs buffer layer

3 n-$Al_{0.63}Ga_{0.37}As$ cladding layer

4 undoped SCH active layer

4a $In_{0.48}Ga_{0.52}P$ optical waveguide layer

4b $In_{0.13}Ga_{0.87}As_{0.75}P_{0.25}$ quantum well layer

4c $In_{0.48}Ga_{0.52}P$ optical waveguide layer

5 p-$Al_{0.63}Ga_{0.37}As$ cladding layer

6 p-GaAs capping layer

7 SiO_2 insulating film

8 p-side electrode

9 n-side electrode

41 n-GaAs substrate

42 n-GaAs buffer layer

43 n-$Al_{0.55}Ga_{0.45}As$ cladding layer

44 undoped SCH active layer

44a $In_{0.48}Ga_{0.52}P$ optical waveguide layer

44b $In_{0.13}Ga_{0.87}As_{0.75}P_{0.25}$ quantum well layer

44c $In_{0.48}Ga_{0.52}P$ optical waveguide layer

45 n-$Al_{0.65}Ga_{0.35}As$ current blocking layer

46 n-GaAs protective layer

47 p-$Al_{0.55}Ga_{0.45}As$ cladding layer

48 p-GaAs capping layer

49 p-side electrode

50 n-side electrode

61 n-GaAs substrate

62 n-GaAs buffer layer

63 n-$Al_{0.6}Ga_{0.4}As$ cladding layer

64 undoped SCH active layer

65 p-$Al_{0.6}Ga_{0.4}As$ first cladding layer

66 n-$Al_{0.65}Ga_{0.35}As$ current blocking layer

67 p-GaAs protective layer

68 p-$Al_{0.6}Ga_{0.4}As$ second cladding layer

69 p-GaAs capping layer

70 p-side electrode

71 n-side electrode

FIG.1

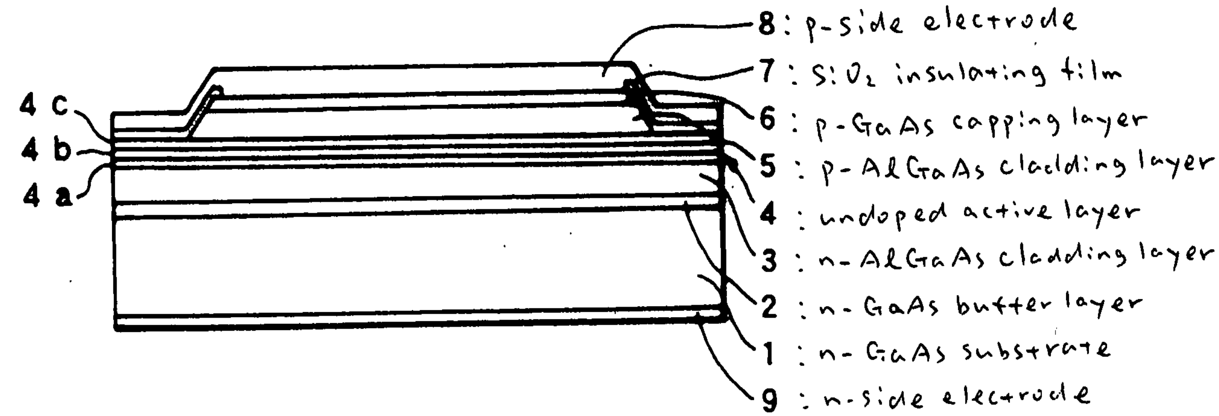

4 c
4 b
4 a
8 : p-side electrode
7 : SiO2 insulating film
6 : p-GaAs capping layer
5 : p-AlGaAs cladding layer
4 : undoped active layer
3 : n-AlGaAs cladding layer
2 : n-GaAs buffer layer
1 : n-GaAs substrate
9 : n-side electrode

FIG. 2

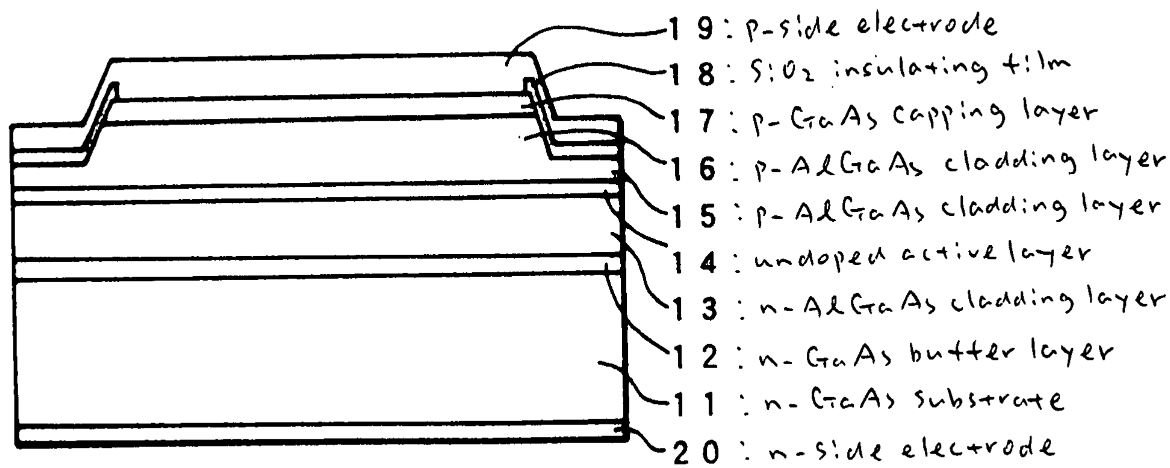
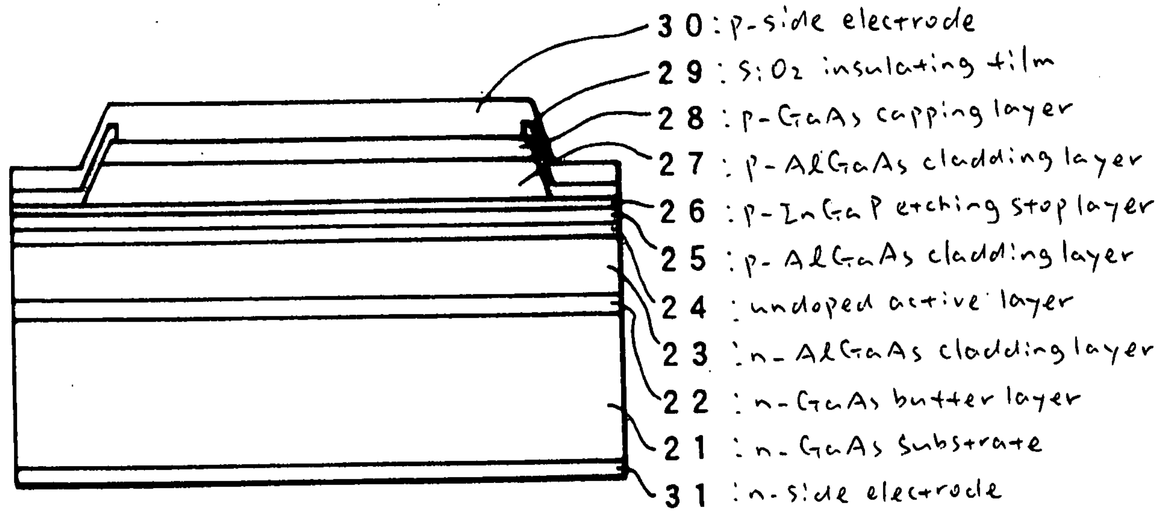
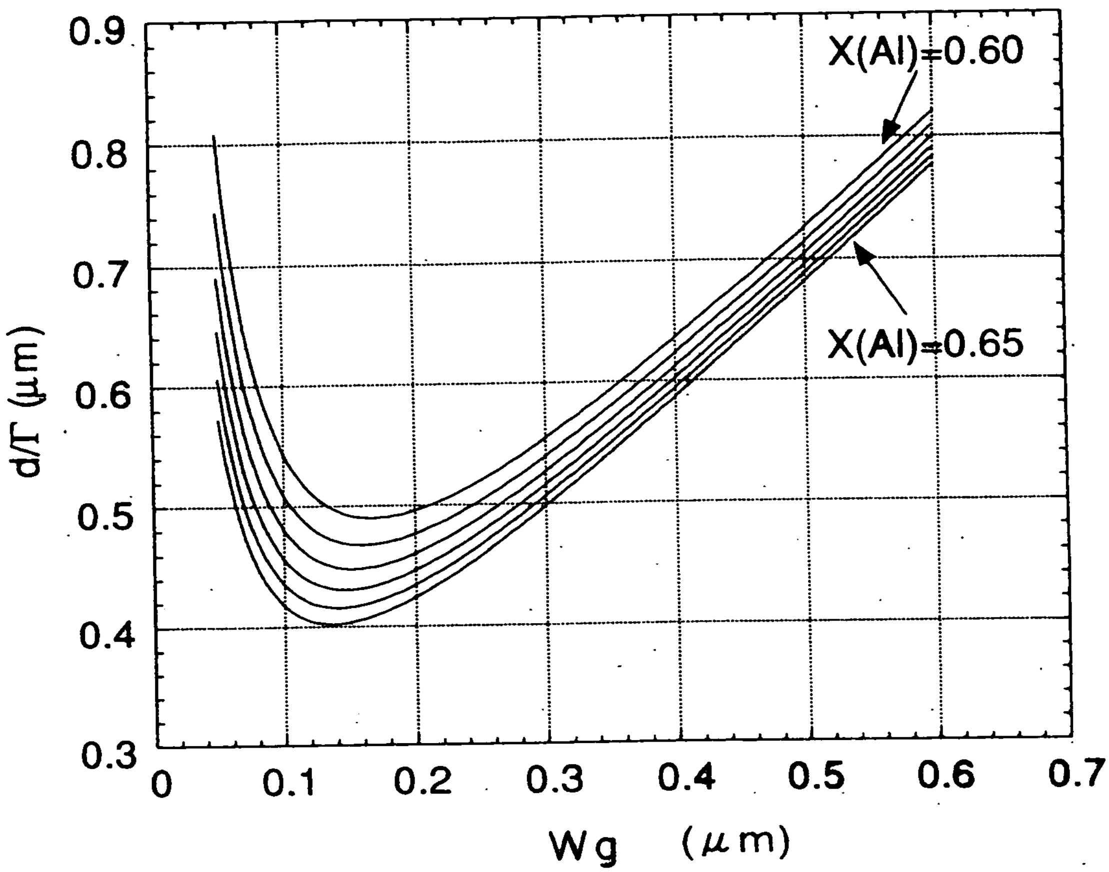

19 : p-side electrode
18 : SiO2 insulating film
17 : p-GaAs capping layer
16 : p-AlGaAs cladding layer
15 : p-AlGaAs cladding layer
14 : undoped active layer
13 : n-AlGaAs cladding layer
12 : n-GaAs buffer layer
11 : n-GaAs substrate
20 : n-side electrode

FIG.3



30 : p-side electrode
29 : SiO2 insulating film
28 : p-GaAs capping layer
27 : p-AlGaAs cladding layer
26 : p-InGaP etching stop layer
25 : p-AlGaAs cladding layer
24 : undoped active layer
23 : n-AlGaAs cladding layer
22 : n-GaAs buffer layer
21 : n-GaAs substrate
31 : n-side electrode

F I G . 4


X(Al)=0.60
X(Al)=0.65
d/T (μm)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Wg (μm)

F I G . 5

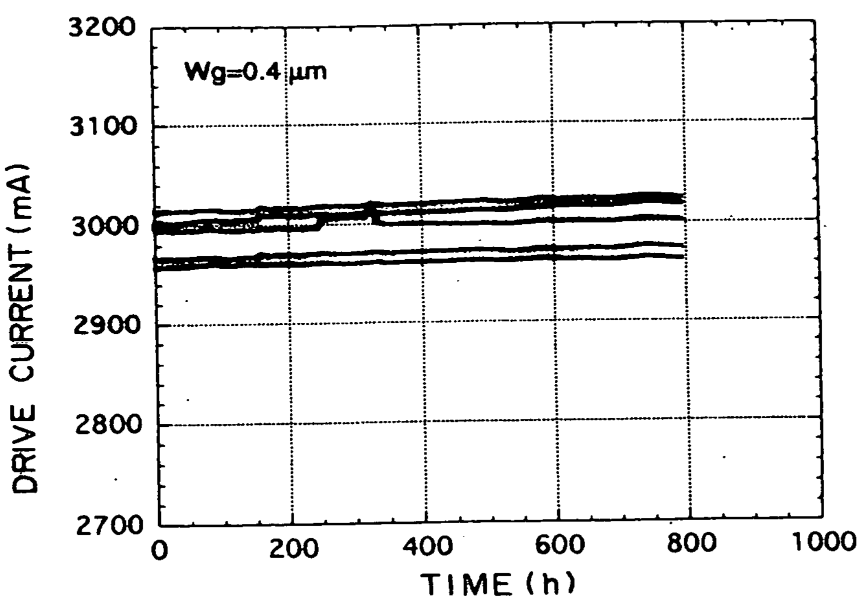

Wg=0.4 μm
DRIVE CURRENT (mA)
3200
3100
3000
2900
2800
2700
0
200
400
600
800
1000
TIME (h)

FIG.6

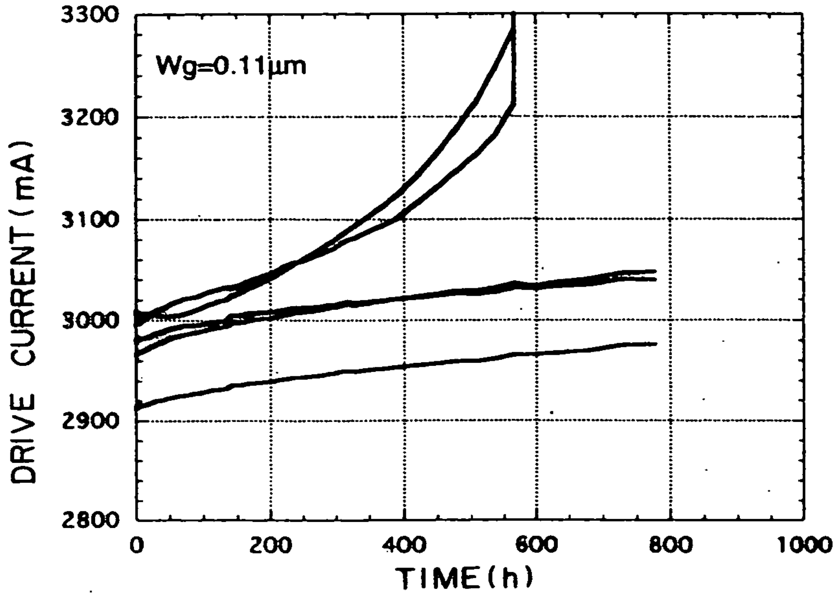

3300
3200
3100
3000
2900
2800
Wg=0.11µm
DRIVE CURRENT(mA)
0
200
400
600
800
1000
TIME(h)

FIG.7

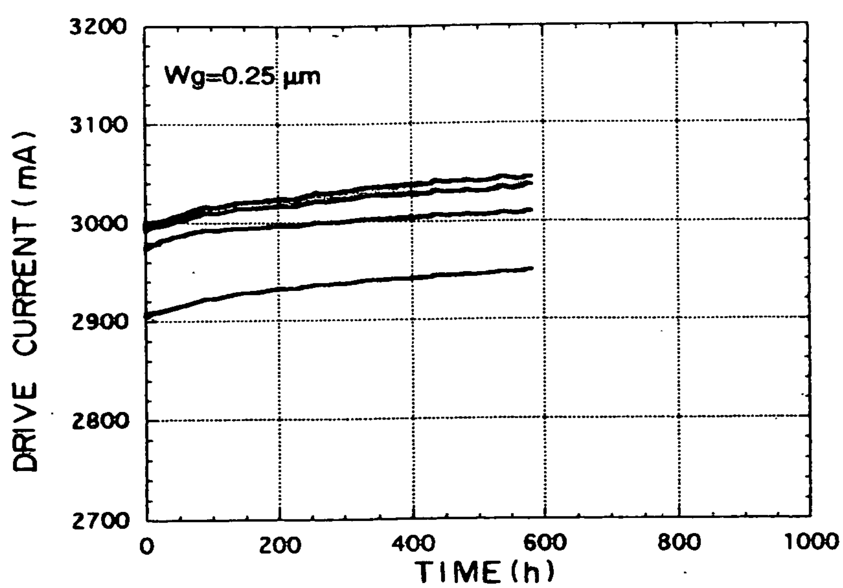

3200
3100
3000
2900
2800
2700
Wg=0.25 µm
DRIVE CURRENT(mA)
0
200
400
600
800
1000
TIME(h)

FIG. 8

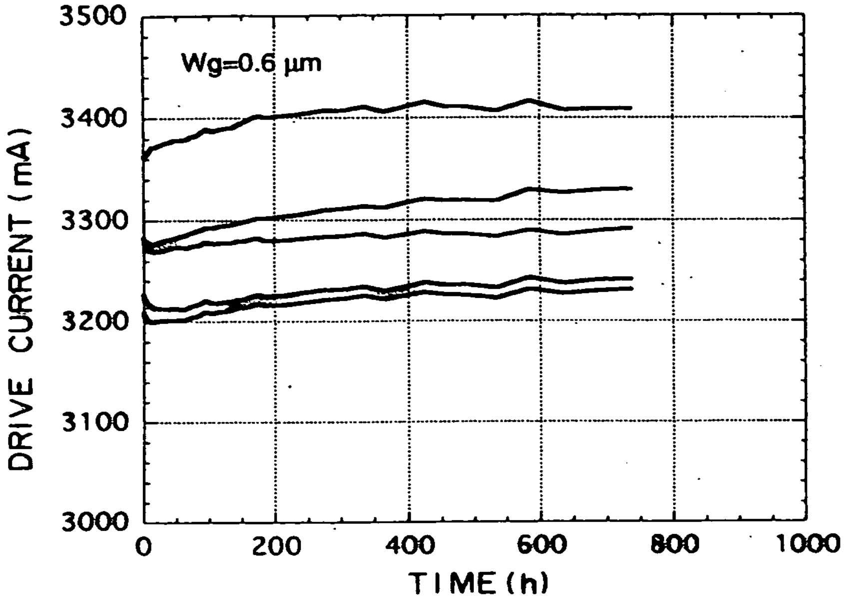
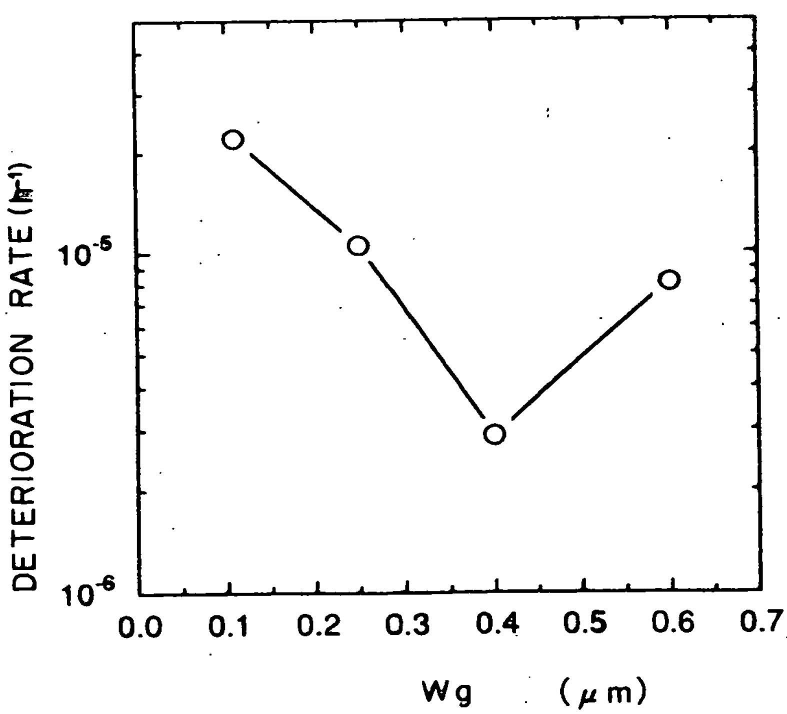
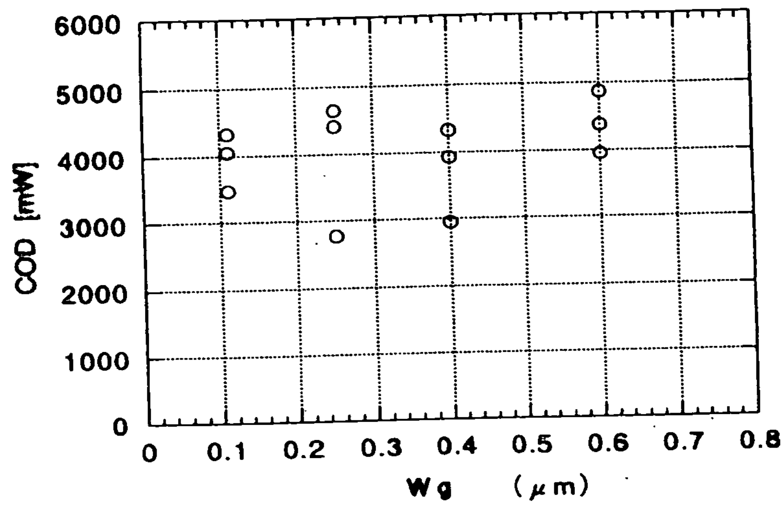

Wg=0.6 µm
DRIVE CURRENT (mA)
3000
3100
3200
3300
3400
3500
TIME (h)
0
200
400
600
800
1000

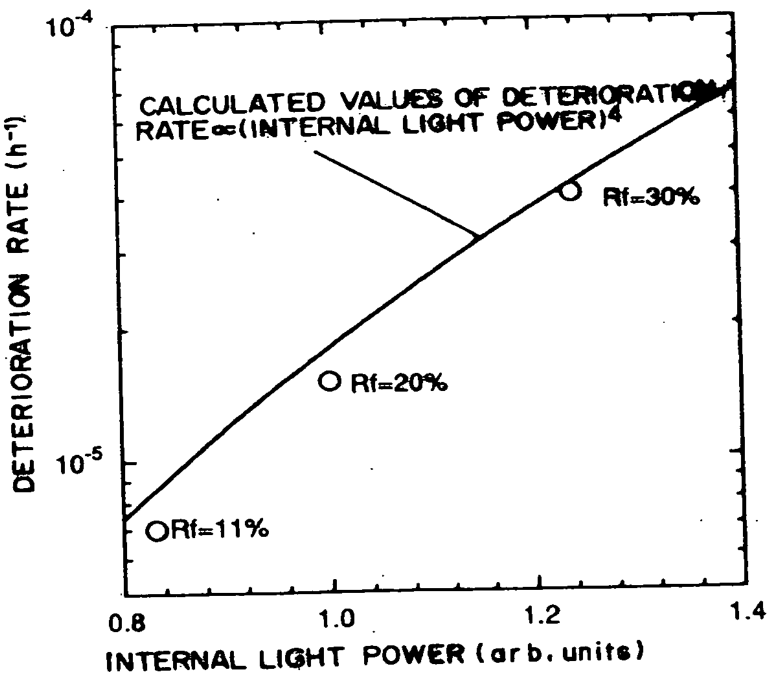
FIG. 9


DETERIORATION RATE (h-1)
10-5
10-6
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Wg (µm)

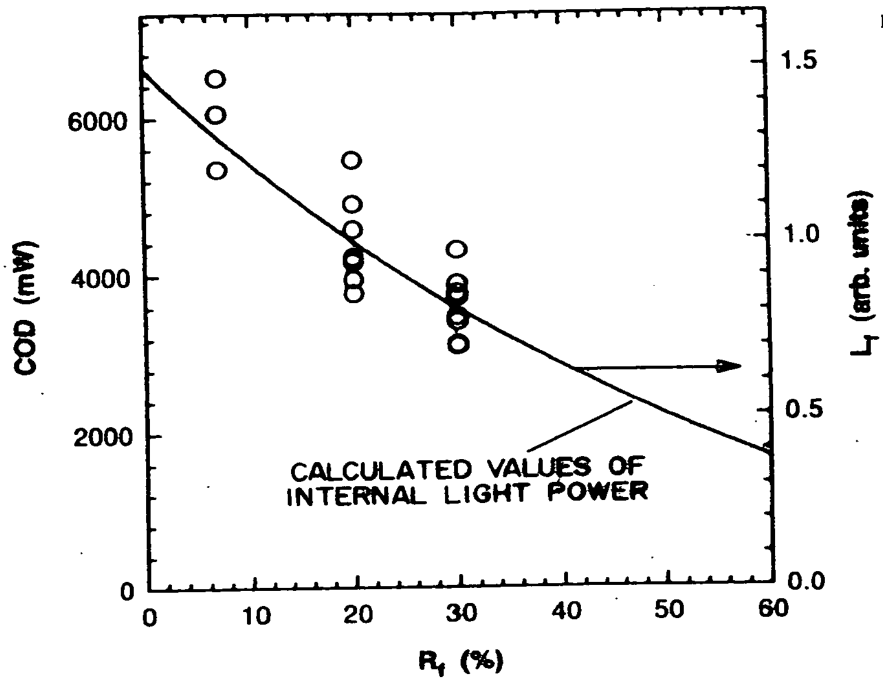
F I G. 10


6000
5000
4000
3000
2000
1000
0
COD [mW]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Wg (μm)

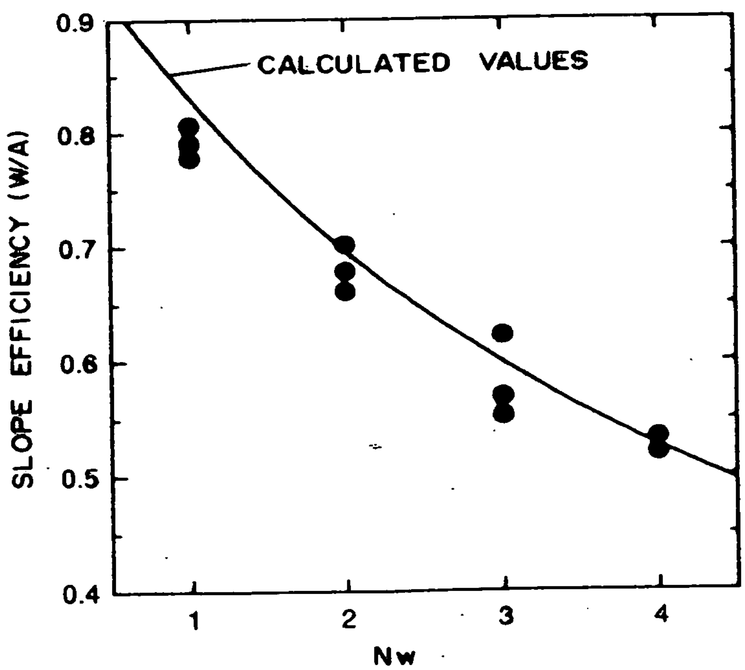
F I G. 11


10-4
10-5
CALCULATED VALUES OF DETERIORATION RATE∝(INTERNAL LIGHT POWER)4
Rf=30%
Rf=20%
Rf=11%
DETERIORATION RATE (h-1)
0.8
1.0
1.2
1.4
INTERNAL LIGHT POWER (arb. units)

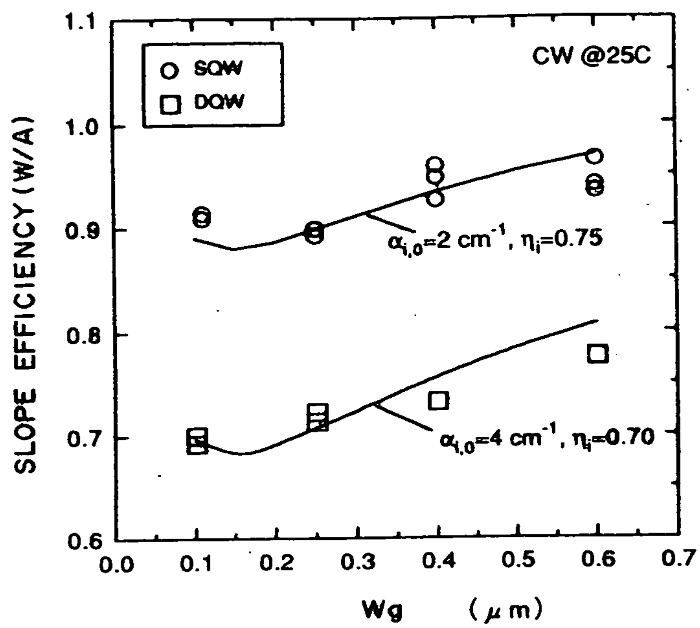
F I G .12


COD (mW)
0
2000
4000
6000
L_f (arb. units)
0.0
0.5
1.0
1.5
CALCULATED VALUES OF
INTERNAL LIGHT POWER
0
10
20
30
40
50
60
R_f (%)

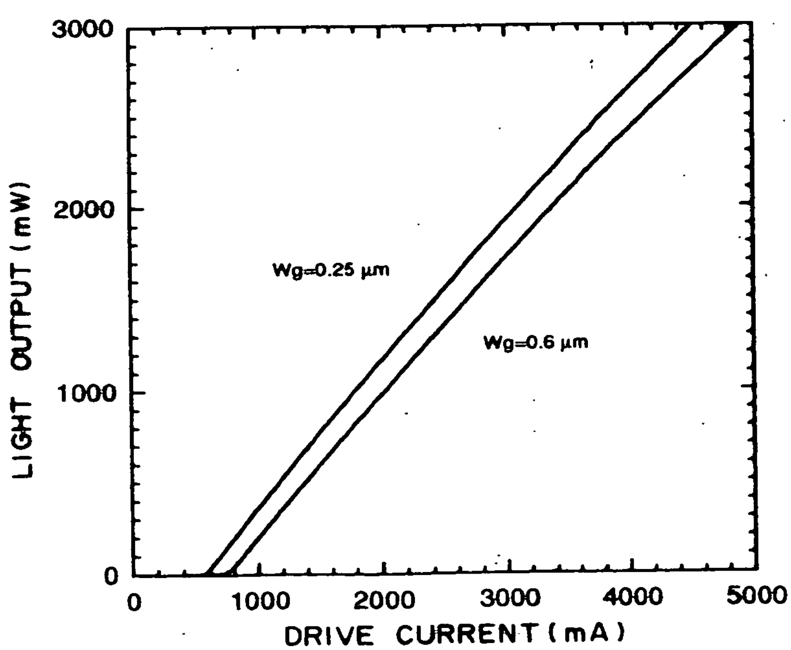
F I G .13


SLOPE EFFICIENCY (W/A)
0.4
0.5
0.6
0.7
0.8
0.9
CALCULATED VALUES
1
2
3
4
Nw

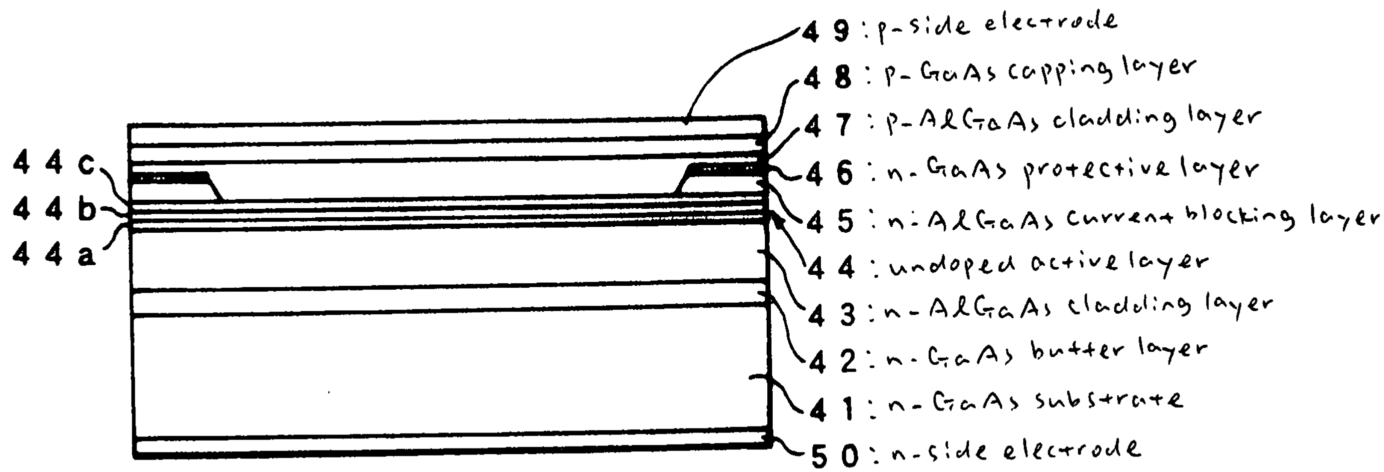
F I G . 14


SQW
DQW
CW @25C
SLOPE EFFICIENCY (W/A)
$\alpha_{i,0}$=2 cm^{-1}, η_i=0.75
$\alpha_{i,0}$=4 cm^{-1}, η_i=0.70
1.1
1.0
0.9
0.8
0.7
0.6
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Wg (μm)

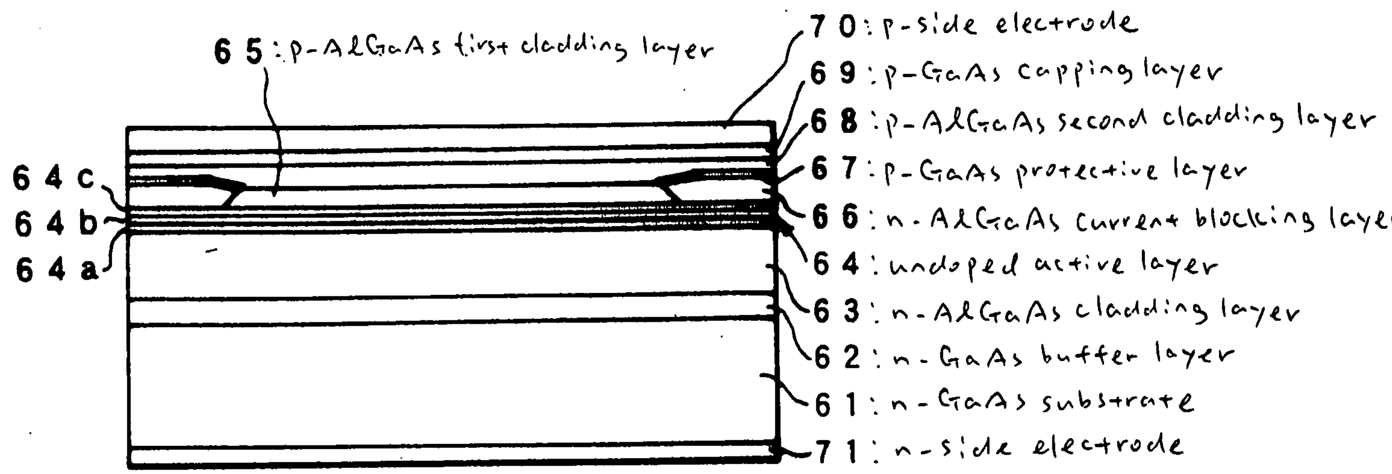
F I G . 15


LIGHT OUTPUT (mW)
3000
2000
1000
0
Wg=0.25 μm
Wg=0.6 μm
0
1000
2000
3000
4000
5000
DRIVE CURRENT (mA)

F I G .16


44c
44b
44a
49 : p-side electrode
48 : p-GaAs capping layer
47 : p-AlGaAs cladding layer
46 : n-GaAs protective layer
45 : n-AlGaAs current blocking layer
44 : undoped active layer
43 : n-AlGaAs cladding layer
42 : n-GaAs butter layer
41 : n-GaAs substrate
50 : n-side electrode

F I G.17



65: p-AlGaAs first cladding layer
64c
64b
64a
70: p-side electrode
69: p-GaAs capping layer
68: p-AlGaAs second cladding layer
67: p-GaAs protective layer
66: n-AlGaAs current blocking layer
64: undoped active layer
63: n-AlGaAs cladding layer
62: n-GaAs buffer layer
61: n-GaAs substrate
71: n-side electrode

【Name of the Document】 Abstract

【Summary】

【Object】 The object of the present invention is to provide a high power semiconductor laser in which the service-life elongating effect of using an Al-free active layer material is enhanced and the long-term reliability is improved.

【Construction】 A semiconductor laser has an active region 4 which includes at least a quantum well layer and upper and lower optical waveguide layers and is formed of $In_xGa_{1-x}As_yP_{1-y}$ ($0 \leqq x \leqq 1$、$0 \leqq y \leqq 1$). Upper and lower AlGaAs cladding layers 3, 5 are formed on opposite sides of the active region. At least one of the optical waveguide layers 4a, 4c is not smaller than 0.25μm in thickness, and a part of the upper cladding layer 5 of AlGaAs on the upper optical waveguide layer 4c is selectively removed up to the interface of the upper cladding layer 5 and the upper optical waveguide layer 4c.

【Selected Figure】 Figure 1